Planning and designing walkable cities: a smart approach

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Abstract

Walking may be considered one of the most sustainable and democratic ways of travelling within a city, thus providing benefits not only to pedestrians but also to the urban environment. Beside, walking is also one of the means of transport most likely subjected to factors outside an individual's control, like social or physical abilities to walk and the presence of comfortable and safe street infrastructures and services. Therefore improving urban conditions provided to pedestrians has positive impacts on walkability. At the same time technological solutions and innovations have the power to encourage and support people to walk by overcoming immaterial barriers due to a lack of information or boring travel and to gain data to understand how and where people travel. Merging these two dimension into a unique approach can drastically improve accessibility, attractiveness, safety, comfort and security of urban spaces.

In this context, this paper aims to draw a more multifaceted context for walkability, where new technologies assume a key role for introducing new approaches to pedestrian paths planning and design and thus for enhancing this mode of transport. Indeed, by combining more traditional spatial-based and perceptual analysis of the urban environment with technological applications and social media exploitation there will be room to better support the decision on and to enhance satisfaction of walking as well as to easier plan and design more walkable cities.

1. Introduction

"Sustainable mobility" is a concept that has been adopted worldwide as a response to the economic, social and environmental issues, such as global GHG emissions and traffic congestion, associated with an extensive use of private cars. At global level, sustainable transport is considered essential to achieve most of the Sustainable Development Goals (SDGs), fixed by the UN 2030 Agenda for Sustainable Development (UN-GA, 2015), especially those related to health, energy, infrastructure, cities and human settlements. The UN-Habitat New Urban Agenda (UN-HABITAT, 2017) wishes for a significant increase in accessible, safe, efficient, affordable and sustainable infrastructure for public transport, as well as for non-motorized options such as walking and cycling, prioritizing them over private motorized transportation.

In the last decades, also the European Union has developed several initiatives and documents in order to encourage a smarter and more sustainable urban mobility: the Leipzig Charter on Sustainable European Cities (2007), the European "Smart Cities & Communities Initiative" (2009), the Toledo Declaration (2010), the White Paper on Transport (EC, 2011), the Sustainable Urban Mobility Plan concept (COM, 2013), confirmed by the more recent Pact of Amsterdam (2016) hope for a sustainable and efficient urban mobility based on public transport, green vehicles as well as on soft mobility (walking, cycling, public space) that ensures accessibility for all and creates healthy environments. The overall goal is to encourage active travel, such as cycling and walking, as sustainable travel modes that respond to both environmental and social needs and help people to have healthier and more sustainable lifestyles.

Despite all the efforts made at International and EU level and the improvements in new, clean vehicle technologies and alternative fuels, private motorized transport continues to remain dominant (EEA-TERM, 2016), especially within urban areas. In fact, by analysing the modal split in 22 main European cities[1] it

[1] Paris, London, Madrid, Barcelona, Lisbon, Vienna, Berlin, Amsterdam, Stockholm, Oslo, Ljubljana, Budapest, Bucharest, Brno, Warsaw, Vilnius, Sofia, Athens, Helsinki, Copenhagen, Florence, Bologna, data extracted from Epomm (http://www.epomm.eu) for the year 2011 (source FIA, 2017).

emerges that slightly over one third of trips are made by car, another third by public transport, and the last third are made on foot or by bicycle (FIA, 2017) and walking covers around one fourth of the overall journeys.

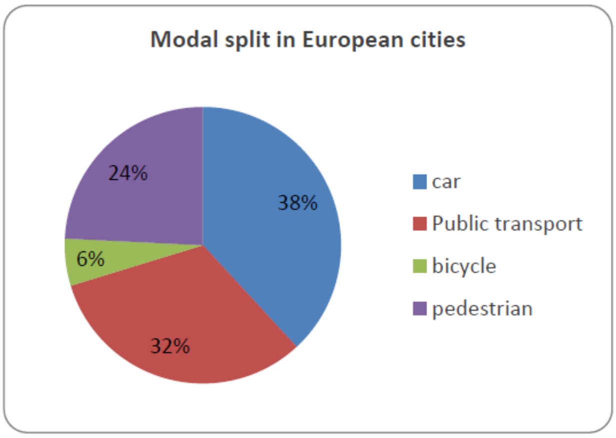

Fig. 1 – Modal split in the main European cities (source FIA, 2017)

Despite in the period 2009 - 2011 walking and cycling increased considerably in certain cities due to the effects of the economic crisis, the car still remains dominant in all EU countries (EEA, 2015), and reducing air pollution and greenhouse gas emissions as well as traffic congestion generated by transport is therefore a major challenge for any sustainable city.

Furthermore, in dense urban areas and over relatively short distances motorized transport is neither efficient, nor sustainable nor safe and it contributes to a sedentary lifestyle, with dramatic consequences on health (WHO, 2016). Conversely, cycling and walking are the most sustainable modes of transport (Kenworthy, 2006), and their promotion together with the development of efficient public transport may be the real feasible, convenient alternatives to reduce levels of car use (UN-HABITAT, 2017; Banister, 2008), to encourage active travels and to make cities healthier and more liveable.

Notably, walking is an important component of almost all trips (Methorst et al., 2010) and may be considered as the most public form of transport (Tolley, 2003) as it is accessible to everyone and it still remains an important mode in its own right (Methorst et al., 2010). Walking is also the best option for travelling within a city, experiencing its socio spatial dimensions (Beyazid, 2013), thus providing benefits to pedestrians as well as to the urban environment. Walking is therefore halfway between a transport system and a form of public life (Lamíquiz and López-Domínguez, 2015), being a very flexible and socially friendly means of transport. Indeed, pedestrians can easily take decisions on the fly and easier interact with other people or activities, can travel for free, without emitting pollution and enhancing their health conditions, can contribute to make streets more vibrant and safer with their mere presence (Lamíquiz and López- Domínguez, 2015). At the same time, walking is the primary form of active travel which has zero emissions, is convenient, and directly addresses lack of physical activity by replacing short, everyday car journeys (Leonard, 2014). Finally, positive impacts on crime, foreclosures and housing values seem to be clearly evident in walkable neighbourhoods (Gilderbloom et al., 2015).

Walking has also positive effects for regenerating and for revitalizing the city. Shafray and Kim (2017) highlight that a walkable city concept has been gaining more and more interest as a relevant approach of urban revitalization, since it concurs to reduce congestion and car dependency, to facilitate outdoor walking and exercise thus enhancing healthy life styles, to promote social interaction through “face-to-face collaboration”. According to Speck (2012), walkable life generates considerable savings for households and is more appealing for specific segments of population, such as creative communities, who prefer living in cities and who are becoming dominant in urban communities. Arup (2016) identifies relevant regenerative effects due to walking, such as:

- Social benefits affecting: health and wellbeing, safety, placemaking, social cohesion and equality.
- Economic benefits including: city attractiveness, the local economy, urban regeneration, and cost savings.

- Environmental benefits to do with virtuous cycles, ecosystem services, liveability and transport efficiency.
- Political benefits associated with leadership, urban governance, sustainable development and planning opportunities.

Walking is also one of the means of transport most likely affected by factors outside an individual's control, which can positively (or negatively) influence it, therefore a supportive built environment may be ensured to promote walking and cycling and to achieve an enduring increase of human activities. Social or physical abilities to walk (Van Cauwenberg et al., 2012), the presence of elevated residential and employment densities, comfortable, well connected and safe street patterns and amenities, presence of a variety of destinations (Handy, 1996; Saelens et al., 2003; Forsyth et al., 2008) are key factors influencing walkability. Since built environment characteristics are of high relevance for walking, and more than for other means of transport (Niemeier and Rutherford, 1994), improving urban conditions provided to pedestrians has a very positive impact on walkability.

Despite these advantages and its importance in the everyday trips, walking remains rather poorly considered as a real and effective mode of transport especially over short distances, and few data have been collected concerning pedestrian mobility. Moreover, the importance and the role of walking as means of transport and as generator of aimlessly trips, such as trips for doing physical activity (Handy et al., 2002), is therefore underestimated.

Steering the use of new technologies towards walking, which are traditionally supportive to other means of transport, such as public and shared transports, might increase comfort and quality of pedestrian mobility thus increasing the related modal split. Since supporting individual non-motorized mobility with smart solutions is not so frequently adopted as a way for increasing pedestrian mobility, the smart city concept refers to sustainable cities and sustainable urban mobility (Garau et al., 2016), which are deeply based on walkability.

Indeed, technological solutions and innovations, such as gamification, social media, mobile apps etc., have the power to encourage and support people to walk by overcoming immaterial barriers due to a lack of information or boring travel and to gain data to understand how and where people travel. Furthermore, they can address the lack of data which may be more easily gained through common mobile phones and technological devices.

A comprehensive smart city concept also foresees the presence of decisive, independent, and aware citizens (Roche et al. 2012), who become a sort of "human sensors" (Fistola, 2013) when they use their personal technologies, such as smartphones, tablets, etc., to gain and to share data and to monitor specific features of an urban phenomenon. Under this viewpoint, pedestrians could be privileged observers and key players for gaining information that public authorities and transport planners hardly manage to achieve.

Moreover, in a smart mobility perspective, where infrastructures and vehicles are closely connected by new technologies and where the introduction of driverless cars and autonomous vehicles is forthcoming, it is essential to equip non-motorized users with proper technological devices and services in order to include them in the Intelligent Transport System, thus providing better accessibility and increasing safety of everyone (Woolsgrove, 2016).

Starting from the analysis of spatial based and perceptual factors, which have been commonly identified as strongly influencing walking by previous studies, this paper aims to draw a more multifaceted context for walkability, where new technologies assume a fundamental role for introducing new approaches to pedestrian paths planning and design and thus for enhancing this mode of transport. Indeed, by combining more traditional spatial-based and perceptual analysis of the urban environment with technological applications and social media exploitation there will be room to better support the decision on and to enhance satisfaction of walking as well as to easier plan and design more walkable cities.

2. Issues and challenges affecting walkability

Walking experience is affected by the cumulative impact of multiple factors and interactions (both positive and negative) between people and the urban environment. Spatial-based and perceived factors are frequently recognized as key factors influencing the decision to walk through their interaction with human senses and attitudes. The more recent adoption of new technologies as supporting tools for moving around a city has been opening a new field of study that considers new technologies themselves as an intermediary for processing, supporting and influencing traditional interactions between people and the urban realm.

2.1 Spatial-based factors

The influence of the built environment on travel demand, with special focus on walking, has been widespread recognized and agreed by many studies (see: Saelens and Handy, 2008; Ewing and Cervero, 2010), which have been developed by different disciplines, from transportation planning to public health studies (Saelens and Handy, 2008). This “contamination”, that conceive walking as a means of transport yielding positive health “side-effects” (Stockton et al., 2016) has presumably made recent transportation research more concerned with human-made environment determinants of non-motorized modes of travel than in the past (Saelens, Sallis and Frank, 2003), stressing the importance of identifying which spatial-based factors influence people’s attitude of walking and in which ways.

The built environment may be generally defined as “the part of the physical environment that is constructed by human activity” (Saelens and Handy, 2008, p.2) and “a composite of a multitude of characteristics” (Handy,1996, p.153), but the literature addressing this topic is vast and several are the elements that form and affect it.

By reviewing research on the relationship between built environment and travel demand, Ewing and Cervero (2010) recall first of all Density, Diversity and Design - the first “three Ds” (Cervero and Kockelman, 1997), as the most cited factors of the built environment affecting travel patterns. The first one is measured by population, dwelling units, employment, building floor area, per unit area; the second one considers the number of different land uses in a given area, while the third one includes street network characteristics within an area.

These three Ds were followed later on by other two Ds: Destination accessibility, which is defined as the ease of access to trip attractions and Distance to transit, which is usually measured as the average length of the shortest street routes from the residences or workplaces placed in an area to the nearest public transit station/stop.

The above-mentioned factors adhere to a large extent to four main dimensions highlighted later on by Handy et al. (2002) as the elements of the built environment that affect the attitude of walking: i) density and intensity of development, defined as the amount of activities present in a given area, mixed land uses; ii) connectivity of the street network, which is the directness and availability of alternative routes through the network; iii) scale of streets, conceived as the three-dimensional space along a street as bounded by buildings; iv) aesthetic qualities of a place, defined as the attractiveness and appeal of a place. Similar elements have been recognized by other authors, such as Frank and Pivo (1994), Saelens et al. (2003), Forsyth et al. (2008), Ozbil (2009).

An extensive review of previous studies on these topics led by Saelens and Handy (2008) shows that the most cited factors characterizing the built environment that influence the attitude of walking are the following: i) accessibility based on distance of or proximity to potential destinations, ii) density, iii) mixed land use, iv) sidewalks (and more generally pedestrian infrastructures), v) connectivity of routes/network. In addition, they highlight neighborhood type, which is generally composite of the above attributes, and aesthetic and safety, which introduce the issue of how the built environment is perceived by pedestrians.

These attributes interlink each other (Saelens and Handy, 2008) and should be considered and managed not separately or individually, but interdependently, in order to promote walking (Stockton et al., 2016). For instance, the availability of destinations together with an interconnected street network makes walking more attractive against other mobility options (Saelens, Sallis and Frank, 2003; Leslie et al., 2007).

The most relevant factors identified by past research as crucial for encouraging walking are summarized in Table 1.

FACTORS	DEFINITION
Density and intensity of development	Amount of activities present in a given area
Connectivity of the street network:	Directness and availability of alternative routes through the network,
Scale of street	Three-dimensional space along a street as bounded by buildings
Accessibility	Based on distance of or proximity to potential destinations
Pedestrian infrastructures	Presence of sidewalks and pedestrian spaces
Mixed land uses	Proximity of different land uses
Aesthetics	Attractiveness and appeal of a place
Safety	Presence of good physical conditions preventing injuries and dangers, such as street lights or pedestrian crossings

Table 1: definition of main factors of the built environment affecting the attitude of walking (authors' elaboration from the analyzed literature)

These factors are frequently mentioned as correlates of the "walkability" concept, which has been investigated by several studies (see Chadwick Spoon, 2005). Walkability has been frequently considered more in terms of specific variables that can be used to designate an area as walkable rather than as a concept itself. Indeed, according with Southworth (2005, p.248), walkability is "the extent to which the built environment supports and encourages walking by providing for pedestrian comfort and safety, connecting people with varied destinations within a reasonable amount of time and effort, and offering visual interest in journeys throughout the network". These variables largely correspond to the above mentioned spatial-based factors.

2.2 Perceptual factors

Beside analysis concerning spatial based features characterizing the pedestrian environment, other studies have been led under another perspective, letting to identify other important factors influencing pedestrian activity. They refer to pedestrian perception of the built environment, which is derived from subjective values (Lee, 2010) and concurs to creating urban environments that support and enhance walking activity as well.

Perceptual factors correlate with the human perception of the built environment, which acts as mediator between the physical features of the environment and walking behaviour (Ewing et al., 2006) since an individual's positive or negative views of the environment may affect his/her attitude of walking (Lee, 2010). Decision to walk depends on how difficult or how ease the action to walk is perceived by people (Methorst et al., 2010), therefore it is essential to understand and to assess the influence of perception on walking behaviours.

This 'humanistic perspective' has been firstly underpinned by important planners and urban designers, such as Jacobs (1961), Lynch (1960), Gehl (1987) and Gehl and Gemzoe (2003) who have been studying how the built environment impacts people's city experience and daily activities within an urban area, by using different approaches.

Studies oriented to investigate the relationship between the built environment and the attitude of walking have also taken into account variables related with perception. The above mentioned review performed by Saelens and Handy (2008) identifies attitudes such as "sense of safety" and "aesthetic qualities", as important elements affecting walking behaviors. These elements derive from how the built environment is perceived by people. Other studies have deepened the issue directly by trying to identify specific perceptual factors (Lee, 2010).

Notably the study "Measuring Urban Design Qualities" led in the framework of the Active Living Research Program (Ewin et al., 2006) represents an important reference. It has been performed by an Expert Panel who extracted a list of key perceptual qualities of the urban environment based on a review of the most relevant urban design literature. The study focuses on urban design qualities, i.e. qualities of the environment that depend on physical features, but reflect the general way in which people perceive and interact with the environment. Nine main urban design qualities affecting walking behaviors have been identified: imageability, legibility, visual enclosure, human scale, transparency, linkage, complexity, coherence and tidiness.

Urban design quality	Description
Imageability	Imageability is the quality of a place that makes it distinct, recognizable, and

	memorable. A place has high imageability when specific physical elements and their arrangement capture attention, evoke feelings, and create a lasting impression
Legibility	Legibility refers to the ease with which the spatial structure of a place can be understood and navigated as a whole. The legibility of a place is improved by a street or pedestrian network that provides travelers with a sense of orientation and relative location and by physical elements that serve as reference points.
Enclosure	Enclosure refers to the degree to which streets and other public spaces are visually defined by buildings, walls, trees, and other elements. Spaces where the height of vertical elements is proportionally related to the width of the space between them have a room-like quality.
Human Scale	Human scale refers to a size, texture, and articulation of physical elements that match the size and proportions of humans and, equally important, correspond to the speed at which humans walk. Building details, pavement texture, street trees, and street furniture are all physical elements contributing to human scale.
Transparency	Transparency refers to the degree to which people can see or perceive what lies beyond the edge of a street or other public space and, more specifically, the degree to which people can see or perceive human activity beyond the edge. Physical elements that influence transparency include walls, windows, doors, fences, landscaping, and openings into midblock spaces.
Linkage	Linkage refers to physical and visual connections from building to street, building to building, space to space, or one side of the street to the other which tend to unify disparate elements. Tree lines, building projections, marked crossings all create linkage. Linkage can occur longitudinally along a street or laterally across a street.
Complexity	Complexity refers to the visual richness of a place. The complexity of a place depends on the variety of the physical environment, specifically the numbers and kinds of buildings, architectural diversity and ornamentation, landscape elements, street furniture, signage, and human activity.
Coherence	Coherence refers to a sense of visual order. The degree of coherence is influenced by consistency and complementarity in the scale, character, and arrangement of buildings, landscaping, street furniture, paving materials, and other physical elements.
Tidiness	Tidiness refers to the condition and cleanliness of a place. A place that is untidy has visible signs of decay and disorder; it is in obvious need of cleaning and repair. A place that is tidy is well maintained and shows little sign of wear and tear.

Table 2 - Definition of the nine Urban design qualities according with the study Measuring Urban Design Qualities (Ewing et al, 2006)

Out of this list another important factor is comfort (Ovstedal and Ryeng, 2002) which may influence the decision to walk (Barros et al., 2015). It is affected by several perceived features of the urban environment, such as microclimate, sounds, visibility, smells, etc. Similar to sense of safety, sense of comfort depends on the reaction of an individual to external surroundings therefore it is considered but not as perceptual quality because it is affected by a degree of objectivity by outside observers (Ewing et al, 2006).
These elements are widely recognized as very influent on the decision to walk; at the same time, it is very difficult to map and to measure them, in order to take them into account within urban retrofitting interventions or once mobility changes addressing walking encouragement should be undertaken.

2.3 Real time information

People moving around cities are more and more experiencing the need of and the opportunities offered by getting information. It is frequently requested to know about the presence of services and shops, the best way to get to a specific place, how safe it is to travel, and so on. To get such information, individuals increasingly use information and communication technologies (ICT), such as sensor-based networks and geospatial-distributed technologies (Roche et al., 2012) and communication technologies (Papageorgiou and Maimaris, 2017). In this way people orient themselves in the physical space and thus effectively navigate themselves (Fang et al., 2015). Mobility can therefore be enhanced with dynamic information for all means of transport, including walking. As a result, a number of Intelligent Transportation Systems (ITS) applications have been developed for all kinds of transport and mobility, showing an interest also for walking (Monterde-i-Bort et al., 2010), even though these applications have been developed mainly for motorized vehicles. Moreover, pedestrian navigation has been one of the most common research topics in the community of spatial behavior of geography, Geographical Information Systems (GIS), as well as outdoor/indoor positioning technology and application (Fang et al., 2015).

The added value of using technological applications is therefore the opportunity that technology provides to automate and integrate spatial and perception factors in order to support pedestrian mobility. Through technology we can integrate components that influence pedestrians' physical and psychological condition by taking into account their individual values, attitudes as well as individual characteristics, such as gender and disability. Further on, we provide an overview of currently available technologies that can be used for developing effective technological applications for pedestrian mobility.

3. ICT for walkable cities

3.1 Currently available technologies

Technology is advancing very fast nowadays. Urban environments have a plethora of electronic sensor systems, GIS data, mobile communication systems, cameras and big data available via an internet connection. Such technologies can be employed for developing effective smart pedestrian mobility systems in order to promote walkability, reduce GHG emissions and improve the quality of life of citizens. An overview is provided below on the most important currently available technologies to be considered when developing an innovative pedestrian mobility system.

Geographical Information Systems

Geographical Information Systems (GIS) are an essential component for the development of any smart pedestrian mobility system. GIS data can be collected from various sources, which can either be commercial, free, private or public. GIS data can also be gathered via crowdsourcing, which makes the pedestrians a contributing part of the system, actively identifying problem areas within a traffic network. Also, social media can be an important source of information, which can be converted into useful data via big data machine learning. Publicly available datasets can be incorporated in the GIS engine, such as OpenStreetMap (Haklay, 2010). Pedestrian mobility data (commercial and public) can be imported in a central GIS database, which can be further used to generate sophisticated maps for the pedestrian mobility system. GIS can contribute to increasing pedestrian connectivity by providing useful information on plausible walking paths and the use of other transport modes.

Electronic sensor systems

Another important technology is electronic sensor systems, which are abundant in our modern cities. Sensors can be used to directly measure the conditions of the pedestrian network. For example, data can be collected via traffic flow inductive loop sensors, air pollution sensors, traffic cameras and so on. Also, smartphones carried by pedestrians, have a whole range of available sensors, including an accelerometer, global positioning system (GPS), gyroscope, sound, picture, video, magnetic field strength, and barometer that can collect geotagged environmental data.

Radio frequency identification

An interesting communication technology that can facilitate navigation is radio frequency identification (RFID). RFID can provide infrastructure to pedestrian communication (Cheng et al, 2012). Pedestrians can be provided with information on traffic signage which can be retrieved from the Internet. Further, RFID tags can monitor pedestrian flows, density, movement and speed of pedestrians. Before implementation of RFID, any privacy issues should be resolved.

Bluetooth

Bluetooth (Mamdouhi et al., 2009) can provide important local information to pedestrians without a need for an internet connection. It can also be used to monitor pedestrian mobility by collecting the MAC address of pedestrians' smartphones and can be used to build origin-destination matrices. Bluetooth can also be very useful for a number of associated devices or sensors such as wearable technology for physical exercise, health monitoring and so on.

Wifi connection

As internet connectivity is essential for any smart pedestrian mobility system, Wifi (Shlayan et al., 2016) can be an important provider of internet access. Since Wifi is a duplex communication technology and supports TCP/IP it can be used by pedestrians for information exchange and services based on location. Further, the various generations of mobile communication -2G (Ma et al., 2008), 3G (Zhao et al., 2013), 4G (Zhioua et al., 2015) and the upcoming 5G (Mumtaz et al., 2015)- are the main technologies for connection with the internet. As a result, pedestrians have available abundant information which can be fed to them in real time.

GPS

Obviously, GPS would be the most important component of any smart mobility system regarding navigation - GPS (Ansari et al., 2014) (USA), GLONASS (Cozzetti at al., 2011) (Russia), Galileo (Margaria and Falletti, 2014) (EU) and BeiDou (Jan and Tao, 2016) (China). Also, a number of services based on location are facilitated with the use of GPS, such a visiting sites and tourist attractions.

ZigBee protocol

As we are living in the era of the Internet of Things (IoT), the ZigBee protocol (Chen et al., 2016) can further enhance the pedestrian mobility experience. ZigBee can facilitate wireless sensor networks (WSN) which can connect a number of devices in the pedestrian network. A less restrictive wireless communication technology is ISM RF (Sichitiu and Kihl, 2008) which provides a more flexible way of connecting devices on a smart pedestrian mobility system.

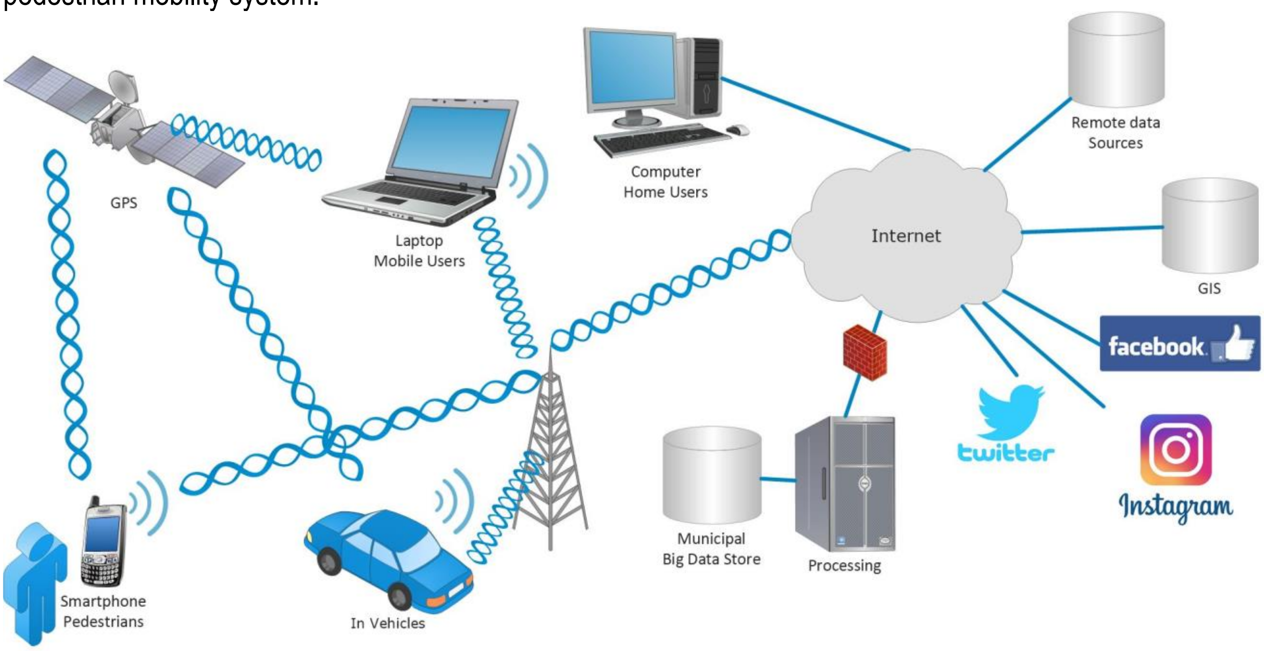

Fig. 2 - Concept diagram that depicts various technologies for walkable cities (authors' elaboration)

3.2. Areas of application

By considering the opportunities offered by the available technologies described above, and relating them to issues ad challenges discussed in par. 2, it is possible to identify three main integration areas where ICT can sensibly improve cities walkability:

- measuring and assessing walkability
- changing behavior.

- gaining data by monitoring pedestrian mobility and providing real time information in order to meet specific and diverse mobility-related needs

Walkability assessment and Measurement

As already mentioned, the spatial-based dimension is highly correlated to the walkability of an urban area. Walkability is frequently considered in terms of specific factors that can be used to designate an area as walkable and there is a number of the GIS-based applications that process different factors allowing to measure and assess the spatial walkability conditions.

Such applications have shown important advantages for assessing walkability in a certain neighborhood in comparison with traditional tools, such as surveys, audits or observational data (Gilderbloom et al. 2015). Furthermore, there is a potential to facilitate the development of indices of walkability that could be used to evaluate new environmental and policy initiatives (Sallis et al., 1998; Bauman et al., 2002; Leslie et al., 2007).

One such walkability index is Walk ScoreTM which automatically calculates walkability for NYC and for all major cities of USA, Canada, Australia, and New Zealand. It is based on a set of two different types of data: Walking routes and distances to amenities and Road connectivity metrics. Walk Score rates the walkability of an address by determining the distance to educational, retail, food, recreational and entertainment destinations (Pivo and Xudong, 2016). Its main objective is to aid the home-buying process (Agampatian, 2014) but it has also become a reference for ranking walkable urban developments in the US (Leinberger and Rodriguez, 2016). Therefore, merging different dimensions made by spatial based factors into a unique tool can drastically improve accessibility, attractiveness, safety, comfort and security of urban spaces.

Supporting walking behaviors

Perceptual factors of the built environment as well as design of urban space are widely recognized as very influent on the decision to walk thus affecting people's behaviors, especially for transportation purposes (Hoehner et al., 2005). At the same time, it is very hard to map and to clearly identify them.

Currently available technologies can be employed in the walking domain for providing a series of different information to pedestrians. As a matter of fact, pedestrian navigation has received increasing attention by the GIS discipline (Fang et al., 2015), and more and more frequently people use GIS-based applications and technological devices for navigating and for assisting pedestrian wayfinding, thus increasing confidence in an unknown environment, or for being alerted on unsafe conditions due to traffic or on insecure environments. GIS based applications can also increase pedestrian comfort navigation using multi-modal environmental sensors, and particularly helping people with special needs (Monterde-i-Bort et al., 2010; Fang et al., 2015). Processed information may be related both to physical and to perceptual factors and are mainly addressed to citizens and to city users in order to support their walking travels and thus to influence their mobility behaviors.

Beyond new technologies supporting pedestrian navigation in pleasant environment, persuasive strategies based on the adoption of new technologies can be useful in facilitating a behavioural change (Wunsch et al., 2015), thus encouraging walking mobility. Many approaches based on: challenges and goal setting, self-monitoring, personalized messages, social comparison, gamification and rewards and so on have been developed so far (Anagnostopoulou et al., 2016).

Self-monitoring is the most frequently used and takes the form of visual feedbacks on CO_2 emissions caused by the users' trips, cost savings and burned calories, etc. Gamification and reward-based competitions have a role in boosting behavioural change as well, especially among youngsters and new generations. Gamification is now incorporated into many running and cycling mobile phone applications where users collect points for the miles they monitor or for reaching a specific target (Coombes and Jones, 2016). In order to achieve good results in this field in terms of engaging even the most reluctant people it is important to personalize persuasion profiles which will be used to tailor interventions to individual user characteristics (Anagnostopoulou et al., 2016).

Data gaining and real-time information

Lack of data about pedestrian trips is twofold. On one side, it affects the knowledge and therefore the decision making that frequently does not consider walking as a real means of transport, but only a necessary part of a

trip represented by other - more important – means; on the other side, real time information to pedestrians could improve their awareness about the different trips possibilities (both in terms of alternatives paths and of trips length).
As a matter of fact, National travel surveys often register neither the shorter trips nor the walking parts of trips made by public transport (Wittink, 2001) or more generally by motorized vehicles (ITF, 2012).
Walking is also considered a derived demand and consequently walking trips not associated with a specific destination, e.g. trips related to leisure and physical activity, are not usually taken into account in the total amount of urban travels (Handy et al., 2002).
Therefore, there is a tendency to underestimate walking flows especially if the walking trips are short (ITF, 2012) both by people who generate them and by transport planners. Even if citizens are all pedestrians at one point in time, pedestrians are not sufficiently represented in urban policies; consequently, urban and transport planners are not adequately influenced by pedestrian needs when they fix strategies and interventions on urban mobility and infrastructures.
Despite this poor attention on walking as a real means of transport, some studies have been performed for reducing the gaps on data collection and for standardizing walking data, in order to raise awareness among urban and transport planners on the importance of walking as a means of transport and on how the traffic measurements can include walking more appropriately. Indeed, walking should be considered as an important allay of public transport because, without walking, buses, trams and trains would have no passengers. A valuable example is the International walking data standards report (Sauter et al., 2016), which aims at providing a standard way of defining and measuring walking. The objective is to establish comprehensive data on walking trips, according with the same degree of accuracy and diligence as other modes, in order to facilitate policy makers and planners to face the extent of walking and to take effective decision for its promotion. London have already adopted this approach for analyzing and then for better planning a walkable city and cities and mobility agencies from Europe and abroad have been strongly invited to do the same, but a strong commitment to invest in this direction is still needed.
This lack of systematic gathering of information represents a limitation and a challenge for pedestrian based studies (Handy, 1996).
According with this issue the European Parliament resolution of 23 April 2009 (COM, 2009) on an Action Plan on Urban Mobility (APUM) gives special attention to potentially useful data on urban transport and mobility, which could be collected through information technology. Crowdsourcing for data collection may be financially effective, especially in cases where the user base is small but enthusiastic and motivated; in such cases crowdsourcing has a huge potential in augmenting the standard data collection procedures by including the opinions of otherwise marginalized groups of users (Misra et al., 2014).
If we consider gaining data systems already in place, both 'Google Better Cities' and 'COWI City Sense - Signal Re-identification' appear to be promising for data collection on active transportation modes use in the future (Steenberghen et al., 2017). COWI has undertaken projects on pedestrians over the past two years, based on increasingly accurate GPS based systems. These systems are used to analyse human mobility around sporting events or community gatherings. However, this application has only been applied in Denmark so far.

4. Conclusions

The above described technologies and applications can greatly contribute to the development of smart walkable cities by strengthening and by supporting all the factors related with perception and features of the built environment in a positive way. Notably, connectivity can be enhanced with GIS, Bluetooth, and mobile communications; safety can be improved by crowdsourcing and image processing from traffic cameras; the choice of comfortable routes can also be facilitated in the pedestrian network through smart sensor technologies and GIS mapping; navigation systems may encourage interactions between pedestrians´ behaviours and the urban environment.
Technological applications may be very supportive also for the decision-making process oriented to develop more walkable cities. By modelling physical and perceptual factors that mostly affect walkability and people's

mobility behaviors it is possible to develop innovative decision support systems able first of all to systematically determine and map minimal existing conditions for walkability and consequently to determine new requirements and interventions to be planned and designed for each street in order to develop more walkable cities. Assessing the walkable conditions provided by the streets is essential to detect if cities have a network of suitable pedestrian streets or not. Identifying necessary interventions and design requirements may also help transport and urban planners and policy makers in better programming infrastructure investments and adopting differentiated and targeted actions for encouraging walkability, such as: improving street lighting, improving footpaths and sidewalks, prioritizing some streets to pedestrians in order to regenerate public spaces and neighborhoods.
Clearly, currently available technologies have a lot to offer when it comes to developing an effective smart pedestrian mobility system. Technology can be a source for innovative solutions to many walkability issues.

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